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MELBOURNE, VICTORIA

REPORT

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DEVELOPMENT AND EVALUATION OF A MICROBURST TEST APPARATUS FOR USE AS A MINIMUM DESTRUCTIVE TEST FOR PARACHUTE MATERIAL

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Development and evaluation of a microburst test apparatus for use as a minimum destructive test for parachute material

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Conventional testing of parachute canopy materials to identify the extent of polymer degradation requires large amounts of material resulting in extensive repairs if the material is found to be sound. A microburst test apparatus designed and built at MRL is capable of testing the canopy in-situ, with a degree of damage confined to a 3.2 mm diameter hole. This does not require repair and fits between a ripstop repeat on canopy material from modern day T-10 parachutes. The microburst unit gives a digital readout for maximum pressure to burst and pressure to burst/time integral. Correlations between these results and those from conventional tensile and Mullens burst tests showed the microburst test results to more closely resemble those from accepted tensile test methods.

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DEVELOPMENT AND EVALUATION OF A MICROBURST TEST APPARATUS

FOR USE AS A MINIMUM DESTRUCTIVE TEST FOR PARACHUTE MATERIAL

1. INTRODUCTION

Parachute canopy design has changed dramatically since the widespread acceptance of steerable canopies. With these has come the requirement for lighter weight, smaller volume parachutes [1]. As the parachute's configuration changes, a better understanding of the stress distributions that occur during inflation is needed so that realistic safety margins can be incorporated into the canopy design.

During the inflation sequence the parachute is subjected to opening forces that stress the canopy material biaxially. To be able to withstand these stresses the canopy material must have approximately the same strength and extension under load in both directions [2]. Generally plain woven materials are used either as a bias or riptstop construction. Both are designed to give increased radial strength.

Most modern parachute types are manufactured from nylon 66 and like most other polymeric materials it loses strength on aging due to thermal oxidative reactions [4,5,6]. Regular testing is required to determine the extent of these losses. The frequency of testing should increase towards the end of the parachute's life which is dependent on the type and concentration of stabilizers added during manufacture. An ideal situation would be for these stabilizers to be effective throughout the parachute's useful lifetime. This is possible if storage conditions are not severe [5]. The usual means of determining this effectiveness and hence the canopy strength is by using mechanical evaluation. Conventional tests such as; breaking force elongation at maximum force and pressure to burst are generally specified. These tests require large amounts of material that has to be removed from the canopy prior to testing. If after testing the parachute is found to be structurally sound, extensive costly repairs are required.

Typical specimen sizes for breaking force determinations are 25 mm frayed width * 300 mm length. These are much larger specimens than required for burst pressure tests which can be done in-situ. For burst pressure tests the major damage is a 30 mm tear running in the direction of the stronger threads. This damage still requires patching, but the effort required for repair is much less than for tensile tests. To adequately test a parachute panel by accepted methods requires approximately 300 mm * 300 mm of material. To overcome this problem of parachute repair a microburst tester was designed, built and evaluated at MRL. The performance criteria for this apparatus was to test the canopy fabric in-situ, to create a degree of damage not requiring repair and to give comparable information on the strength characteristics of a canopy material to conventionally accepted tensile tests.

2. EXPERIMENTAL

2.1 *Tensile tests*

All testing was performed at 20 $\pm$ 2°C, 65 $\pm$ 2% relative humidity.

Breaking force measurements were done in the warp direction only on fabric samples frayed to a width of 25 mm. All samples were tested using a Goodbrand testing machine at a grip separation of 200 mm and a constant rate of extension of 110mm/min. A constrained beam and L.V.D.T. were used for force measurements.

2.2 *Mullens Burst Test*

Biaxial burst tests were done using a Goodbrand-Mullens burst tester in accordance with Australian Standard AS 2001.2.4-1979. A kyowa pressure transducer was incorporated into the system to enable the calculation of "impulse loading" and give a more accurate signal read-out. The specimens were sampled at random.

2.3 *Microburst Tester*

Microburst tests were done using the microburst tester described in section 4. The air flow driving the indentor was measured at five litres/minute on a Matheson flowmeter from a gauge pressure of 96 KPa. The time to rupture the original ripstop material was approximately 0.5 seconds. The mass of the piston/spindle and indentor must be 117 $\pm$ 5 g. The microburst tester gave results as pressure to burst and a pressure to burst/time integral "impulse loading". These results were verified using a Bascom Turner 8120 recorder at a sampling time of 10 milliseconds. The working drawings for the microburst tester are available as M.R.L. Engineering drawings No. 3325.

3. MATERIALS

The physical characteristics of the nylon 66 plain woven taffeta material and the nylon 66 plain woven olive drab ripstop material are given in Table 1.

3.1 Accelerated Aging of Nylon 66 Material

Both materials were thermally aged in a fan forced oven at temperatures of 90°C and 100°C. Due to differing rates of oxidation the undyed nylon taffeta was aged for 2,4,8,16,32,64 and 128 days. Whereas the olive drab dyed ripstop material was aged for 2,4,8,16,32,64,128 and 256 days.

4. APPARATUS

A cross-sectional diagram of the apparatus is shown in Figure 1. It consists of these major components. These are:

(a) Base
(b) Fabric clamping block
(c) Piston and spindle

A further diagram showing all relevant dimensions is given in figure 2.

The overall dimensions of the apparatus are:

(d)	combined height of base and fabric clamping block	150 mm
(e)	diameter of the fabric clamping block and base	100 mm
(f)	height of base	100 mm
(g)	height of fabric clamping block	50 mm

A detailed description of each of these components is as follows:

4.1 Base

The base is divided into an upper and lower unit separated by a pigmented natural rubber diaphragm of 0.8 mm thickness. These units are joined by eight 6.4 mm diameter socket headed bolts which pass through the lower unit and diaphragm and screw into the upper unit. The lower unit has an internal chamber 40 mm in diameter * 20 mm in depth. Two 2 mm holes are bored from the outside in to the chamber. These holes accommodate the air intake and the air outlet to the pressure transducer. A large 4.5 mm hole is bored directly opposite the air intake port, this hole houses a pressure relief valve.

The upper unit has an internal chamber of 47.5 mm diameter * 45 mm depth. This chamber acccommodates the piston. Two air relief ports pass from the internal chamber to the outer diameter of the unit. One port is 3.4 mm diameter and, at the top of the chamber, the other is a larger 6.2 mm diameter port situated 12.7 mm above the rubber diaphragm. The upper unit also has a centrally located hole drilled through its summit and into the top of the chamber. This accommodates the piston spindle. A teflon bush is press fitted into the hole to stop the piston spindle from sticking during testing. A reed switch inserted level with the top of the internal chamber and 5 mm from its edge activates the air release for the pressure transducer. The reed switch is held in position with "silastic" adhesives. The clamping surface of the upper unit has 6 annular 4 mm deep corrugations designed to hold the fabric under test. These corrugations are 5 mm, 10 mm, 15 mm, 20 mm, 30 mm and 40 mm from the unit centre. The clamping surface is coated with natural rubber.

4.2 *Fabric Clamping Block*

The fabric clamping block is a 10 mm diameter * 50 mm high cylinder containing a centrally located 5 mm diameter hole down its length. The under surface of the block contains 6 annular hemicylindrical shapes to engage the corrugations on the clamping surface of the base upper unit. The surface of the clamping block is also rubber coated and is loaded by a 20 Kg mass. This ensures no movement of the sample during testing.

4.3 *Piston and Spindle*

The piston is machined from a bakelite/fabric composite. The piston is 25 mm long with a 22 mm diameter and 6 mm high necked region. This necked region has a 45 mm diameter ferrite sleeve attached, the height of which is level with the top of the piston. Centrally inserted into the top of the necked region of the piston by a 4 mm thread * 0.8 mm pitch is the indentor, the base of which is a cylinder of 19 mm diameter and 10.0 mm height. The indentor plunger is a 3.17 mm diameter * 31 mm high spindle topped with a 3.17 mm ballbearing which has 1.016 mm accurately ground from its upper surface. The bakelite base region of the piston was machined to be a slide fit into the upper unit chamber.

The base and the fabric clamping block were machined from aluminium but any suitable material may be used. The indentor was made from mild steel.

4.4 *Replacement of Spindle or Indentor*

After replacing a spindle or indentor, comparative testing using representative samples is required to determine the suitability of the replacement. Results obtained for both the burst pressure and the integral of burst pressure versus time "impulse loading" for the replacement indentor are to be within the statistical limits determined for the old indentor (Appendix 1). Newly ground indentors sometimes give low readings due to sharp edges around the indentor surface. This is overcome by lightly sanding these edges with fine emery cloth (400).

4.5 *Circuitry*

A stabilized D.C. power supply provides the requirements of the pressure transducer, signal processing circuitry and the operation of the various relays and a solenoid valve. The pressure transducer is a solid state integrated circuit (National L*1830GBW) having a working range of 0-300 psi (0-2100 kPa approx.). The signal from this is conditioned to form a digital display scaled as kPa. The signal is also processed to provide the integral. The pressure to burst/integral is switched on by a solenoid valve situated in the air line, likewise the signal from the transducer is switched off by a reed switch set in the top of the cylinder block. The switching on or off of the air supply induces RF spikes of considerable amplitude which significantly effect the pressure and integral values. It is therefore essential to eliminate these from the signal evaluation circuitry. Time delays of the order of 20 ms were built in at the initiation and termination of the experiment eliminating the unwanted voltage spikes. An analogue output of pressure can be stored in memory and be recalled when required to provide a suitably scaled pressure/time curve. A photograph of the operating system is given in Figure 3.

5. RESULTS AND DISCUSSION

The breaking force, elongation to maximum force and energy to maximum force for undyed nylon 66 taffeta thermally aged at 90°C and 100°C are given in Figures 4 and 5. In all instances the rate of loss increases with time and temperature of test. Both Figures show the rate of loss of breaking force and elongation to maximum force to be similar. Both the breaking force and the elongation to maximum force are traditionally regarded as sensitive measures for determining the condition of fabrics. A much more sensitive measure is the area under the force/elongation curve (shaded area in figure 6), known as the energy to maximum force. This is not unexpected, as the diagram resembles a right angled triangle with dimensions of height (breaking force) and base (elongation). Simple trigonometry shows a four fold reduction in the overall area for a 50% reduction in both the amplitude and base. The olive drab ripstop material although degrading at a slower rate than the undyed taffeta material shows the same effect. Figures 7 and 8. The force/elongation curve is similar to that for undyed material and the energy to maximum force is again the most sensitive to change.

5.1 *Burst Pressure*

5.1.1 *Mullens Burst Test*

The percentage property loss for the respective nylon materials tested on the Mullens burst test apparatus is similar to that obtained for the tensile test specimens. Figures 9 and 10. As no energy to fracture measurements were made due to the difficulty in accurately measuring the fabric distension, the total "impulse loading" or burst pressure versus time integral was determined. This measurement although not relating to the energy

to fracture, is very sensitive to change. The reason for this sensitivity is the same as that described previously for the energy to fracture and results from the triangular shape of the curves. Figure 11. If "implulse loading" measurements are used for comparative testing, then the rate of loading and the time base must be constant for all measurements.

Burst strength specimens, when tested showed more brittle behaviour than the tensile test specimens. This is confirmed by examination of the burst pressure versus time ("impulse loading") trace, Figure 11B where no yield point is apparent. The reasons for these differences are discussed in section 5.3.

5.1.2 Microburst Tester

Comparison of the maximum burst pressure and tensile breaking force for both nylon materials tested show similar strength losses for all aging temperatures Figures 12 and 13. The curves for the pressure to burst versus time integrals ("impulse loading") and the energy to maximum force show a suprising likeness particularly at longer aging times, even though as previously stated they are not directly related. Figure 14. This likeness was designed by predetermining the gauge pressure (96 kPa) and gas flow rate (5 ℓ/min) necessary to give strength losses calculated from impulse measurements comparable to those from energy to fracture measurements. Figures 4 and 12 for undyed nylon 66 taffeta and Figures 7 and 13 for olive drab dyed ripstop material. This problem of predetermining the gauge pressure and flow rate could be overcome by modifying the apparatus so fabric displacement could be measured. This would then allow energy to fracture measurement to be obtained.

5.2 Statistical Significance

The sample mean and standard deviation for both nylon 66 undyed taffeta and olive drab dyed ripstop materials tested using the microburst tester are given in Appendix 1. The students "t" test was used to determine confidence in results for sample populations of unaged olive drab ripstop material tested some months apart. These results showed that at the 99% confidence level the sample means were identical. (Refer Appendix 1.)

5.3 Scanning Electron Microscope

A study of the fracture morphology of the nylon fabrics was made to try to gain some insight into the fracture mechanisms during fibre rupture. Fracture morphology of the unaged tensile ruptured specimen is typical of nylon 66 filaments tested at a low strain rate [7,8,9]. These show a ductile fracture surface with a "V" notch area of initiation Figure 15. Both burst test samples differ in fracture surface to those from tensile tests. They show a large number of kink bands at the fibre surface and a lesser degree of ductility. Figure 15. This decrease in ductility probably results from the higher strain rates used for both burst tests. Similar kink bands have been observed by Goswami [7] for nylon 66 ruptured in the flex-fatigue mode. These

bands usually occur on the underside of bent filaments due to compressive stress. As the bands observed for the burst specimens appear to be circumferential we believe they result from a compressive wave progressing along the fibre at failure. Close examination of the fracture surfaces from microburst samples show some indication of "shearing" due to the indentor shape but this is not the predominant mode of failure. Fibre breakages are due mainly to classical crack migration.

6. CONCLUSIONS

The microburst tester is a robust unit capable of determining strength and the more sensitive pressure to burst/time integrals ("impulse loading") for nylon 66 parachute canopy materials. This was determined by testing undyed taffeta and olive drab dyed ripstop materials aged at 90°C and 100°C for periods ranging to 256 days. These materials showed progressive strength losses and comparative testing between conventional tensile tests, mullens burst tests and microburst tests under the conditions stated show the microburst test results to more closely approximate those from conventional tensile tests. The microburst tester is designed to give a digital readout for the maximum burst pressure and the integral of burst pressure versus time ("impulse loading"). The "impulse loading" measurements are a more sensitive measure of strength losses and can be used for comparative testing provided the rate of loading and the time base remain constant throughout the experiments. This is achieved by having a constant gas flow rate and gauge pressure. Selective settings of gas flow rate and gauge pressure can be made prior to testing to give strength losses calculated from "impulse loading" measurements that correlate directly with those from energy to maximum fracture measurements. For the current work the gas flow rate was 5 l/min and the gauge pressure was 96 kPa. To overcome this manipulation and further improve the apparatus a means of measuring the fabric displacement could be incorporated. This would give energy to fracture measurements and direct comparisons between energy to fracture measurements for both tensile and burst tests could be made.

The major advantages of the microburst tester are:

1. It does not require the removal of large areas of cloth prior to testing.

2. Parachute canopy testing can be done in-situ.

3. The resultant damage after testing does not require repair. The damage is confined to one ripstop repeat unit.

4. Microburst strength losses relate closely to those from conventional tensile tests.

5. Both maximum burst strength and maximum impulse are given as digital readouts.

6. The essential features of piston/spindle and indentor can be readily reproduced.

7. ACKNOWLEDGEMENTS

The authors wish to thank Mr C. Stewart and other members of the MRL Design office for their contributions to this program.

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APPENDIX 1

Mean strength losses for nylon parachute materials tested using the microburst test apparatus are as follows:

T=90°C

SAMPLE UNDYED NYLON 66 TAFFETA

DAYS AGED	0	2	4	8	16	32	64	128
Sample Mean	62.5	59.0	61.0	57.8	58.1	56.0	50.0	45.9
Standard Deviation	3.0	2.5	2.5	1.8	2.0	2.9	2.1	1.5

T = 100°C

DAYS AGED	0	2	4	8	16	32	64	128
Sample Mean	62.5	62.2	60.3	57.0	54.9	52.1	48.9	36.8
Standard Deviation	3.0	1.6	2.0	2.6	0.9	0.8	2.9	2.7

T = 90°C

SAMPLE OLIVE DRAB DYED RIPSTOP

DAYS AGED	0	2	4	8	16	32	64	128	256
Sample Mean	55.6	55.4	54.3	54.7	55.5	52.8	52.3	47.3	44.3
Standard Deviation	2.8	0.1	0.1	3.5	1.5	2.3	0.1	1.6	1.6

T = 100°C

DAYS AGED	0	2	4	8	16	32	64	128	256
Sample Mean	55.6	53.8	55.4	54.7	54.9	51.2	52	43.6	36.6
Standard Deviation	2.8	2.5	1.6	1.1	0.9	1.7	0.2	2.8	1.3

To determine confidence in tests results from samples tested at different times, the students "t" test was done on two populations of unaged olive drab ripstop material tested some months apart.

POPULATION	1	2
SAMPLE NUMBER	99	10
SAMPLE MEAN	57.33	55.65
VARIANCE	15.7	5.02

At the 99% confidence level both population means were found to be identical.

TABLE 1

PHYSICAL CHARACTERISTICS OF CANOPY MATERIALS TESTED

TEST	PLAIN WOVEN UNDYED TAFFETA	PLAIN WOVEN OLIVE DRAB RIPSTOP
Weight (g/m^2)	44.5	34.7
ends	40	43
picks	39	43
Breaking Strength (N) per 25 mm width		
warp	231	217
Extension (%)	23.5	20.9
Filaments/yarn		
warp	12	10
weft	12	10
linear density		
warp	5.3	3.6
weft	5.2	3.5
Fibre diameter (μm)	21.2	20.1
Delustrant as TiO_2 (%)	0.28	0

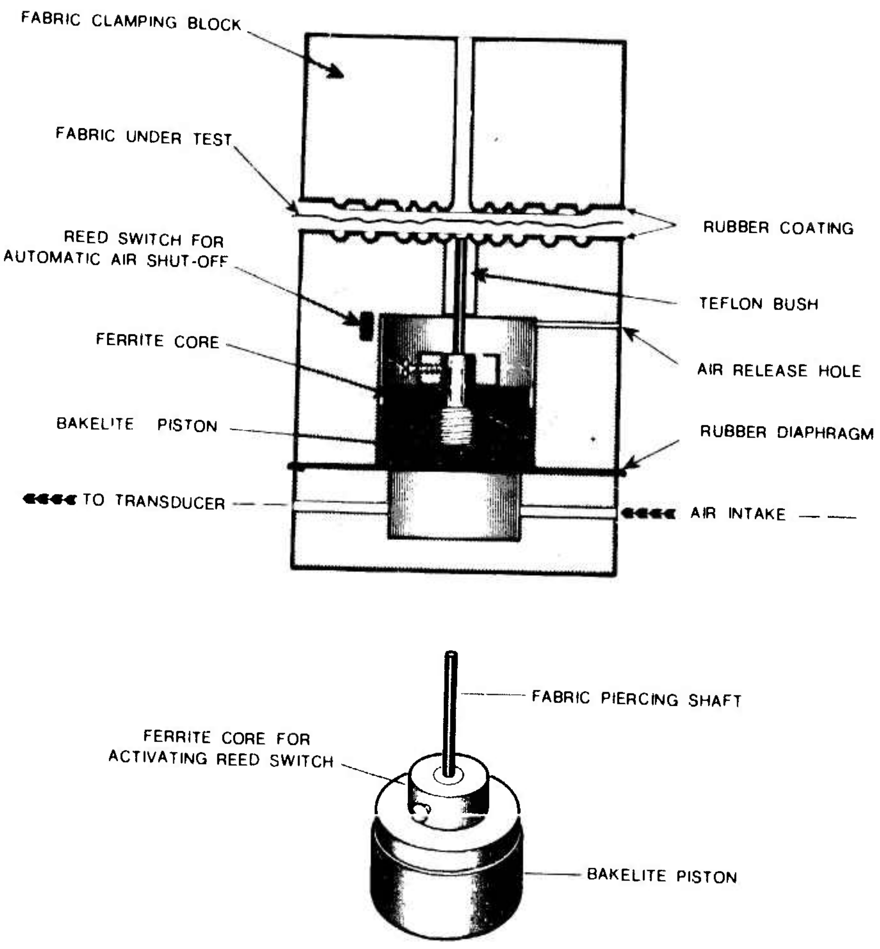


FIGURE 1. Cross-sectional diagram of the microburst test apparatus.

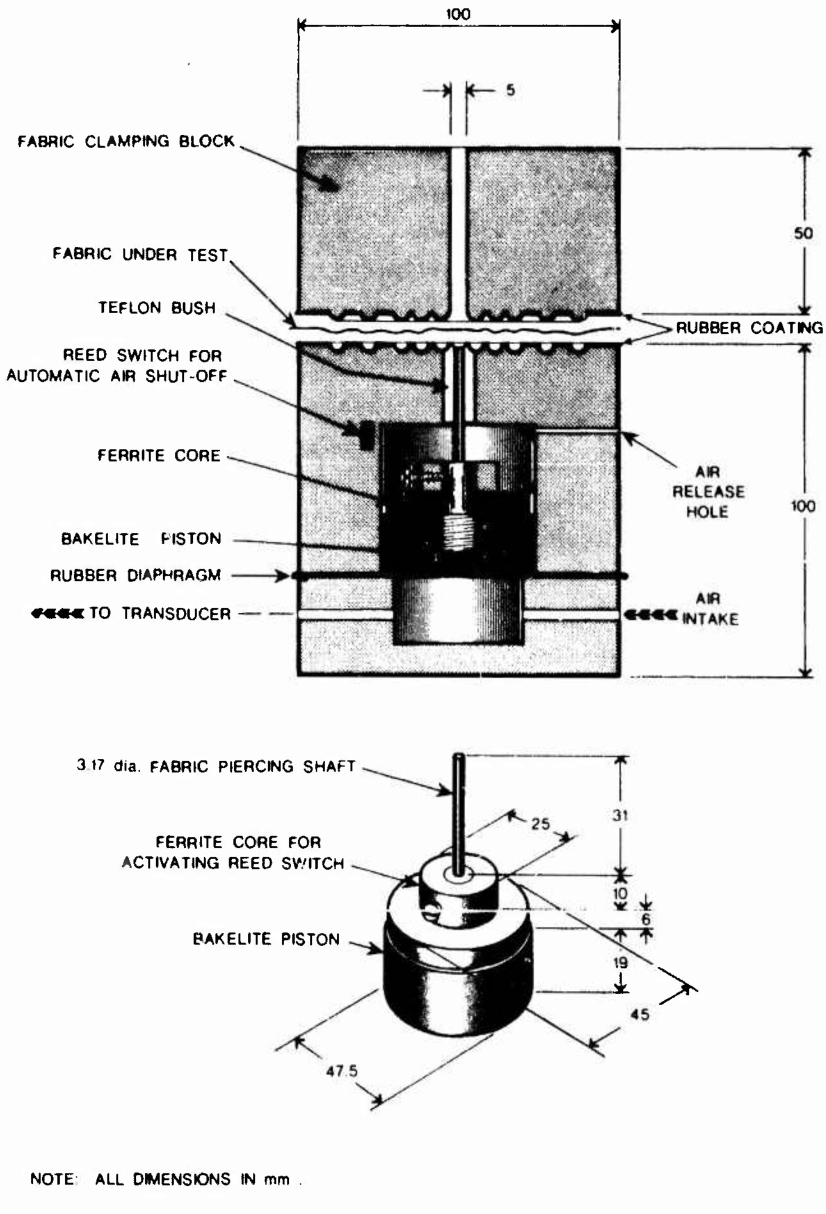


FIGURE 2. Labelled cross-sectional diagram of the microburst test apparatus.

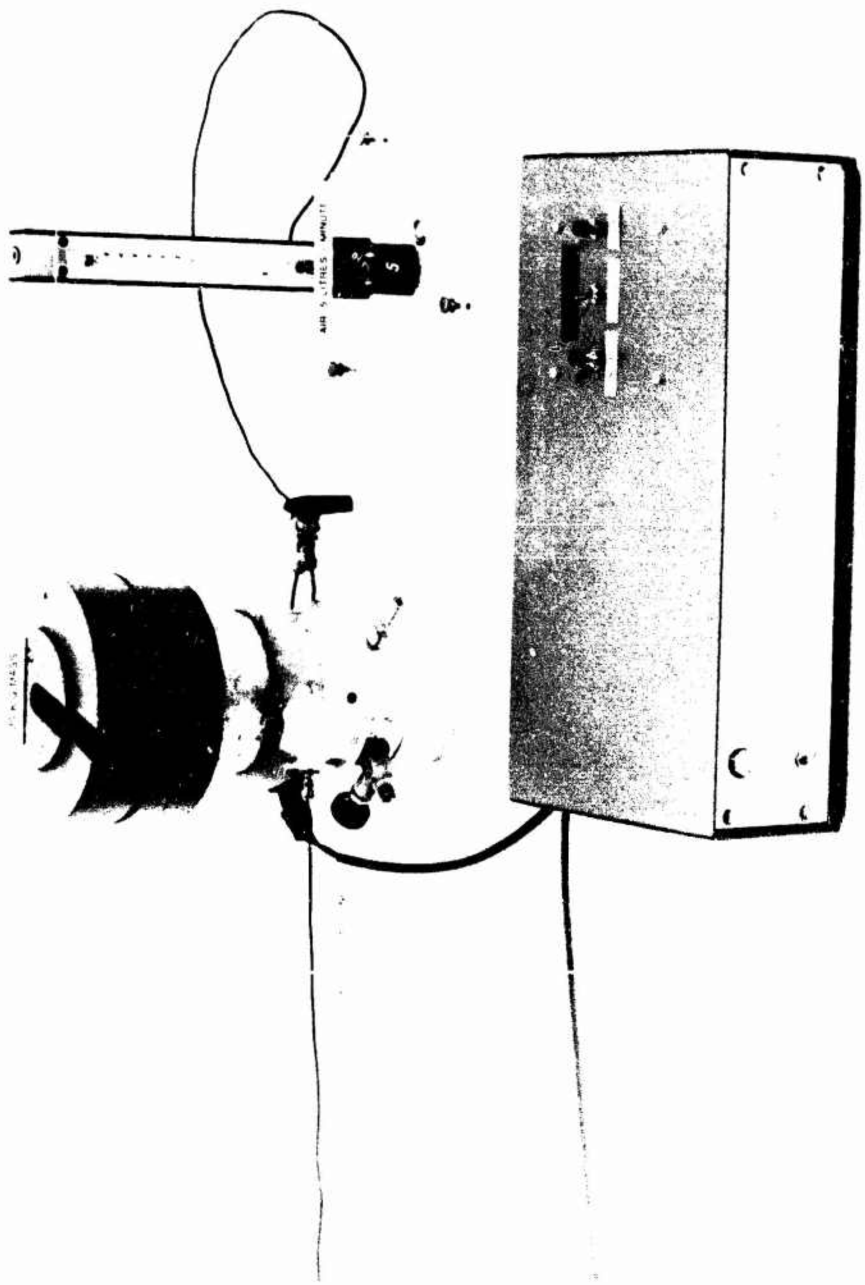


FIGURE 3.   Operating microburst test system.

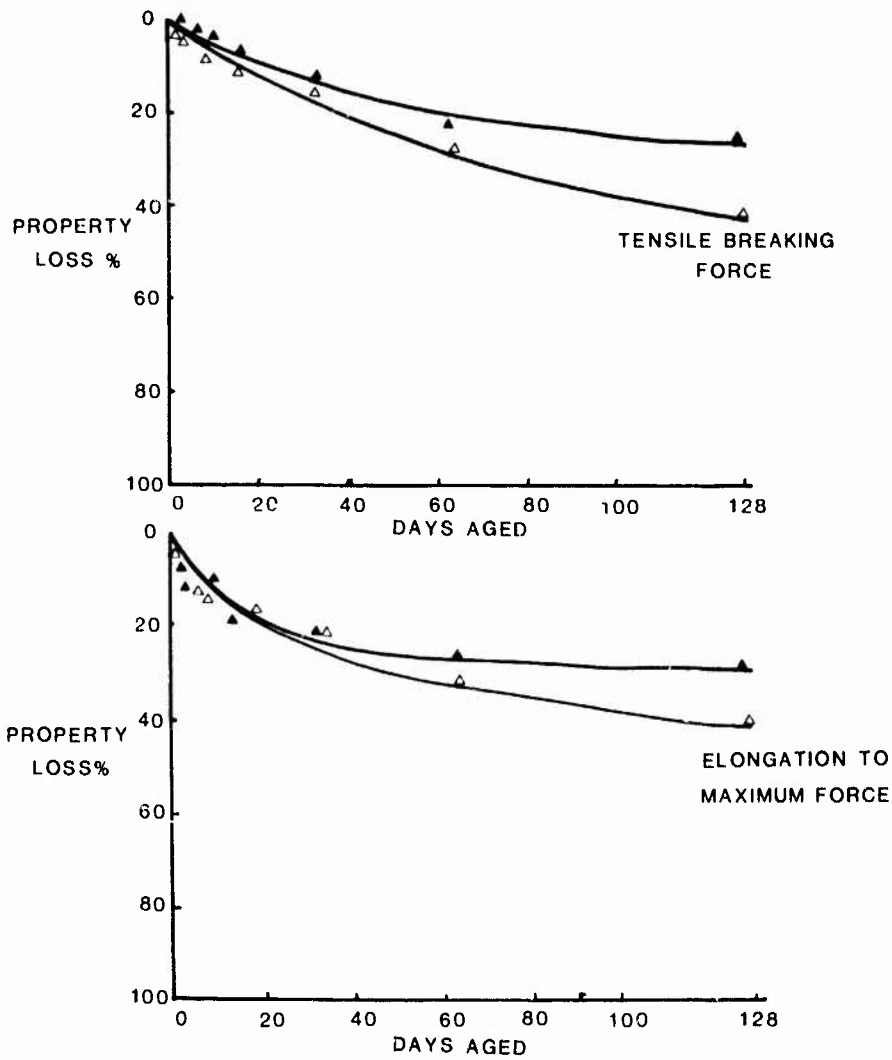


FIGURE 4. Undyed nylon 66 taffeta thermally aged at 90°C and 100°C
▲ 90°C
△100°C

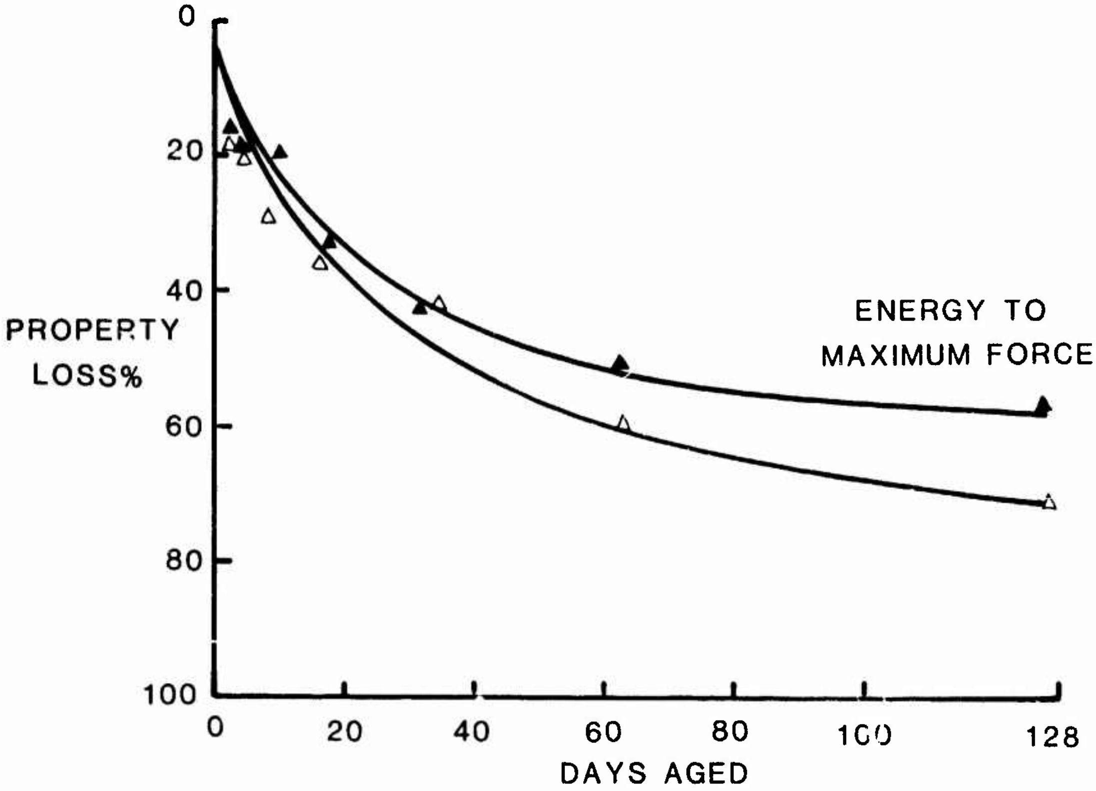


FIGURE 5. Energy to maximum force calculated from the area under the stress strain curve for undyed nylon 66 taffeta, thermally aged at 90°C and 100°C.

▲ 90°C

△ 100°C

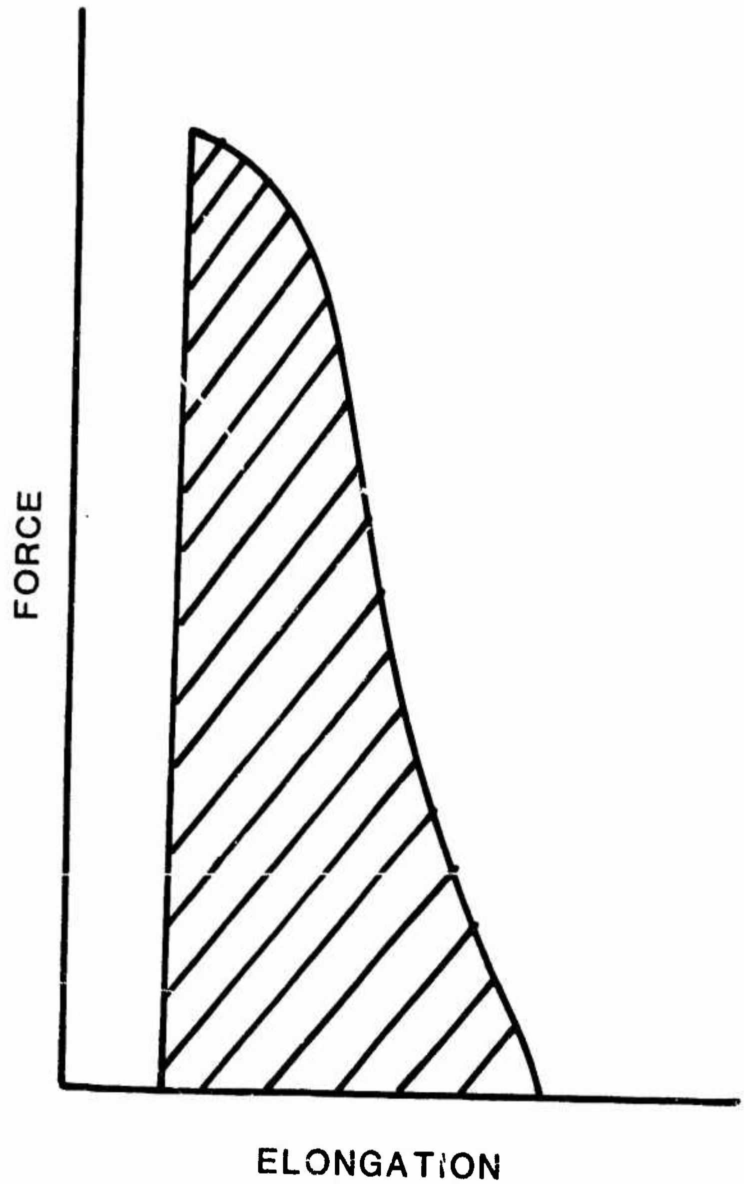
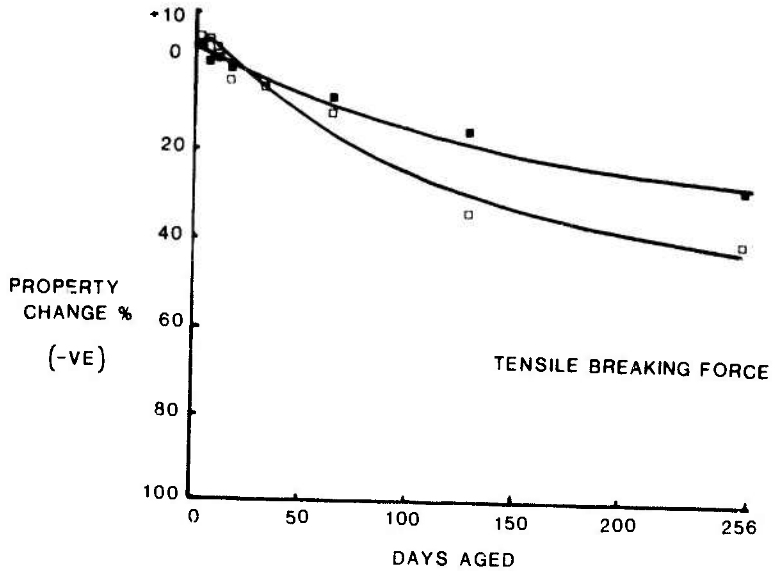


FIGURE 6. Energy to maximum force for undyed nylon 66 taffeta material.



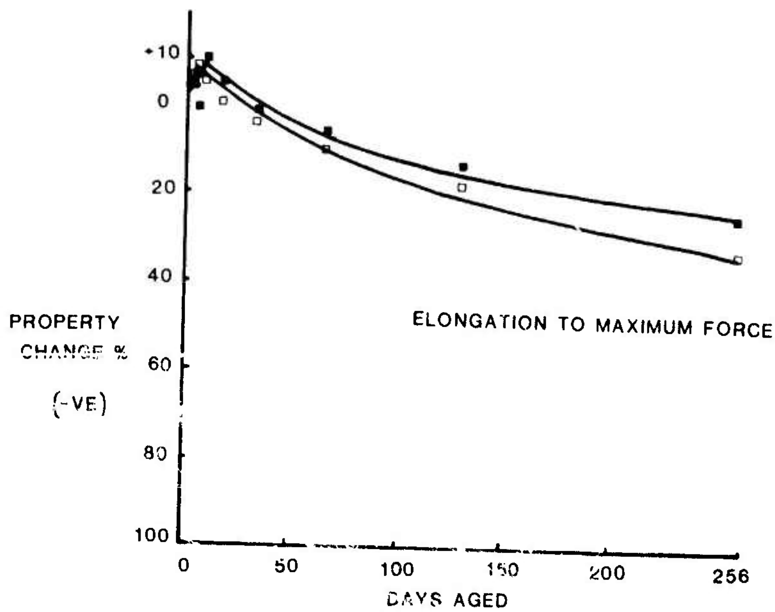


FIGURE 7. Nylon 66 olive drab ripstop material, thermally aged at 90°C and 100°C.

■ 90°C

□ 100°C

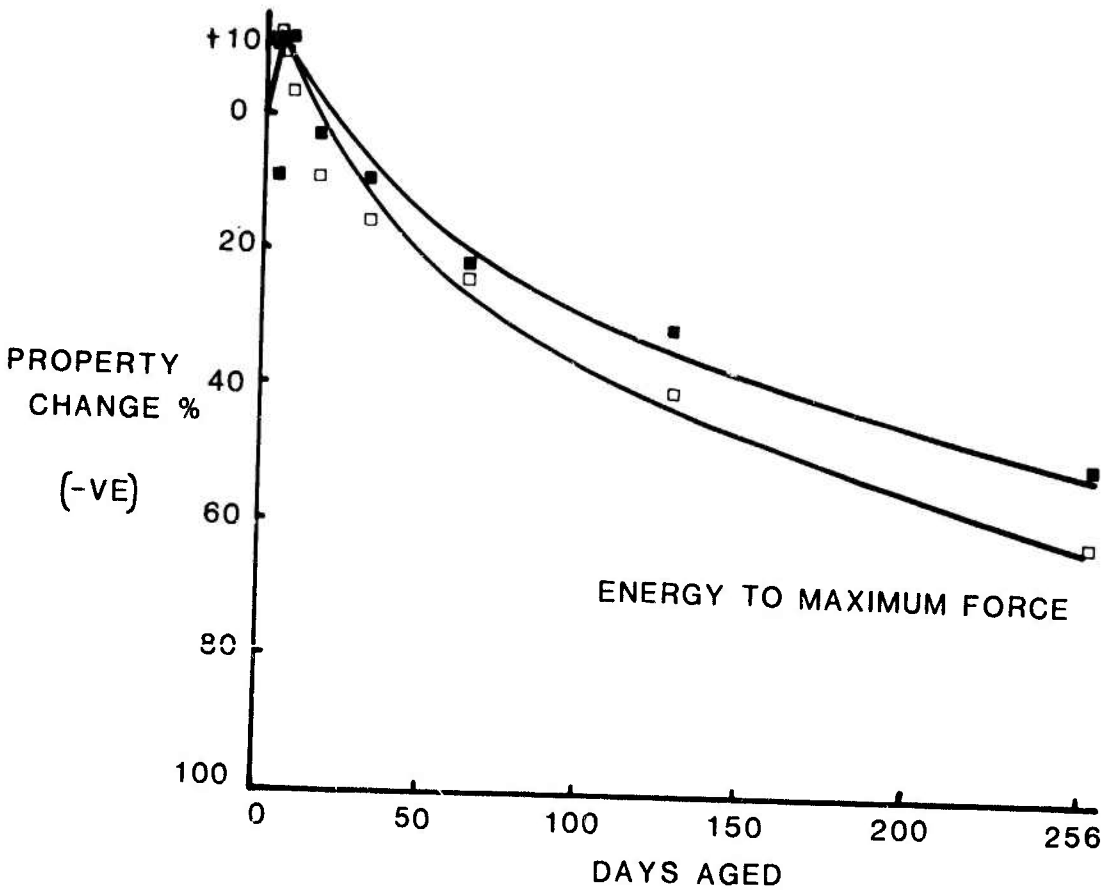


FIGURE 8. Energy to maximum force calculated from the area under the stress strain curve for nylon 66 olive drab dyed ripstop, thermally aged at 90°C and 100°C.
■ 90°C
□ 100°C

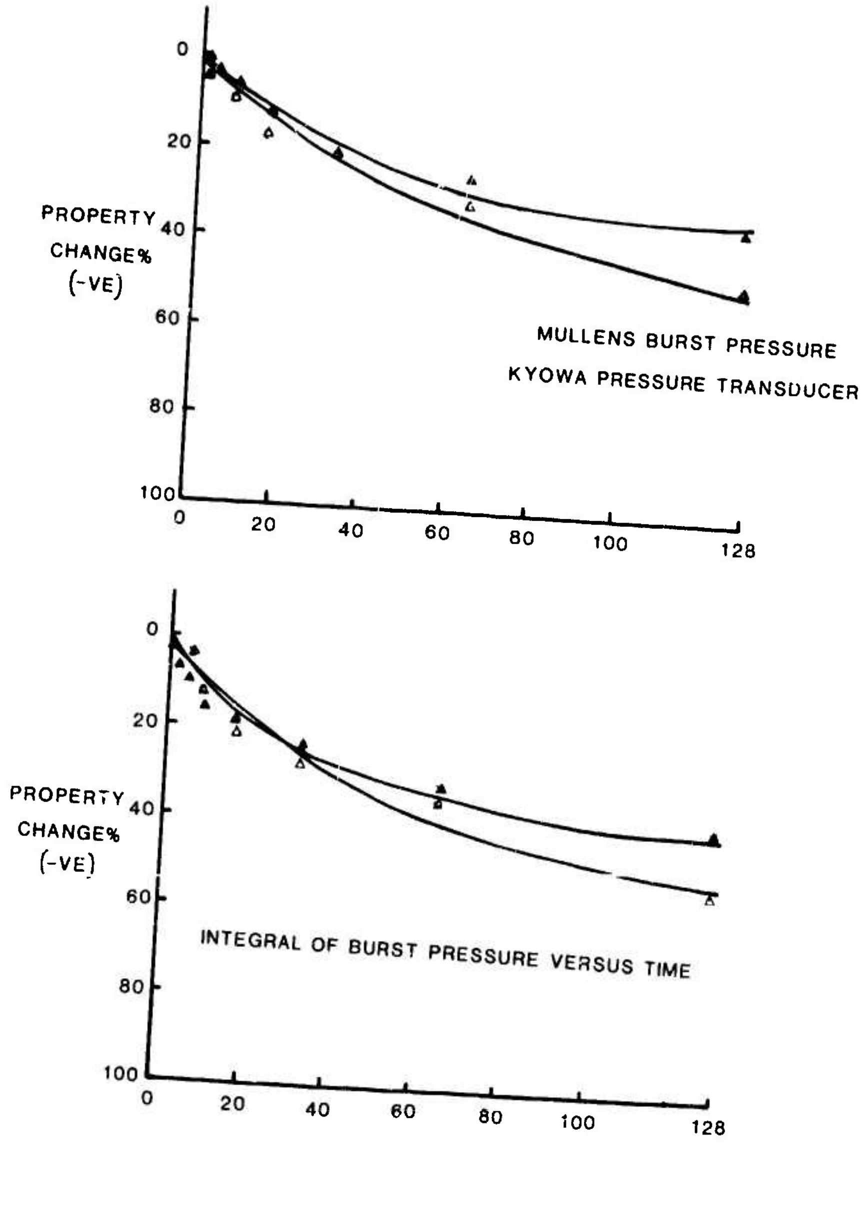


FIGURE 9. Mullens type burst test for undyed nylon 66 taffeta thermally aged at 90°C and 100°C.

▲ 90°C

△ 100°C

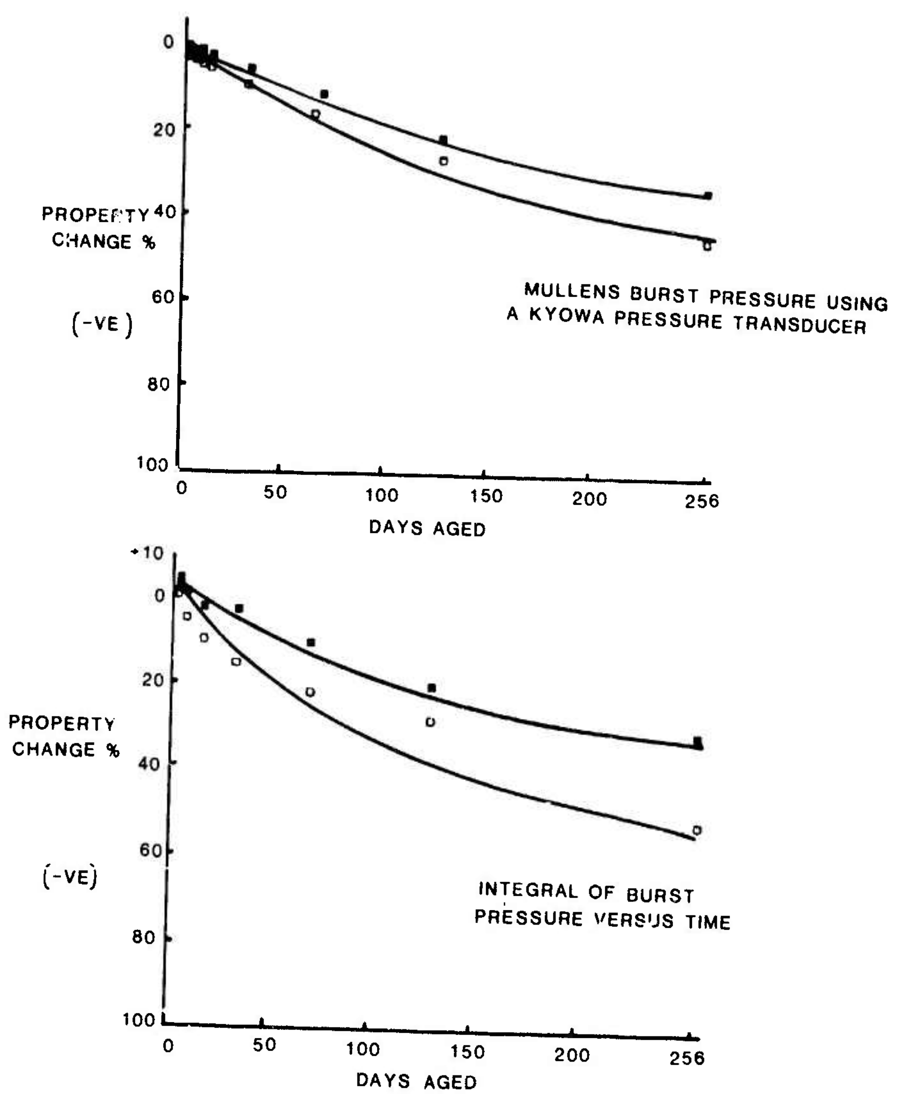


FIGURE 10. Mullens type burst test for nylon 66 olive drab dyed ripstop, thermally aged at 90°C and 100°C.

■ 90°C

□ 100°C

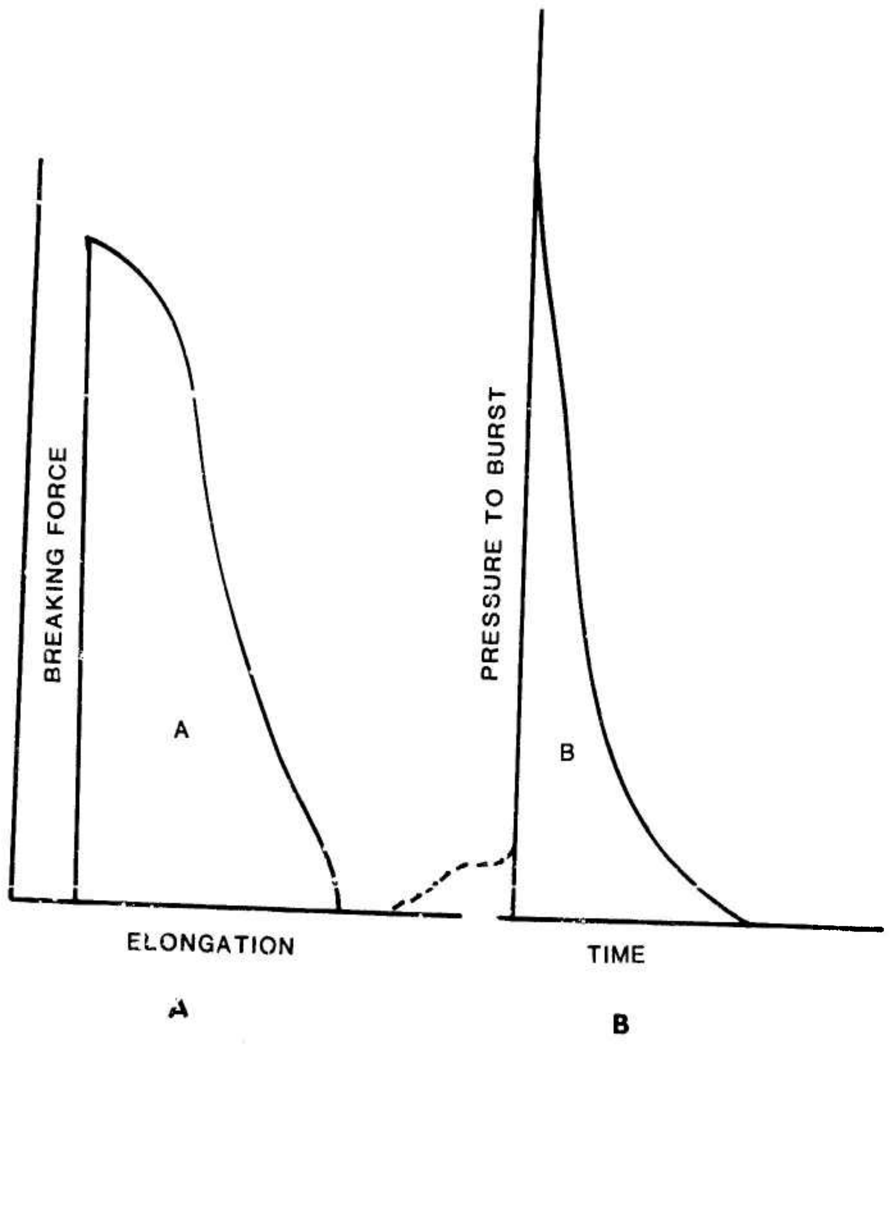


FIGURE 11. Nylon 66 taffeta, unaged.

A Breaking Force/Elongation curve.
B Pressure to burst/time (Impulse) for Mullens burst test.

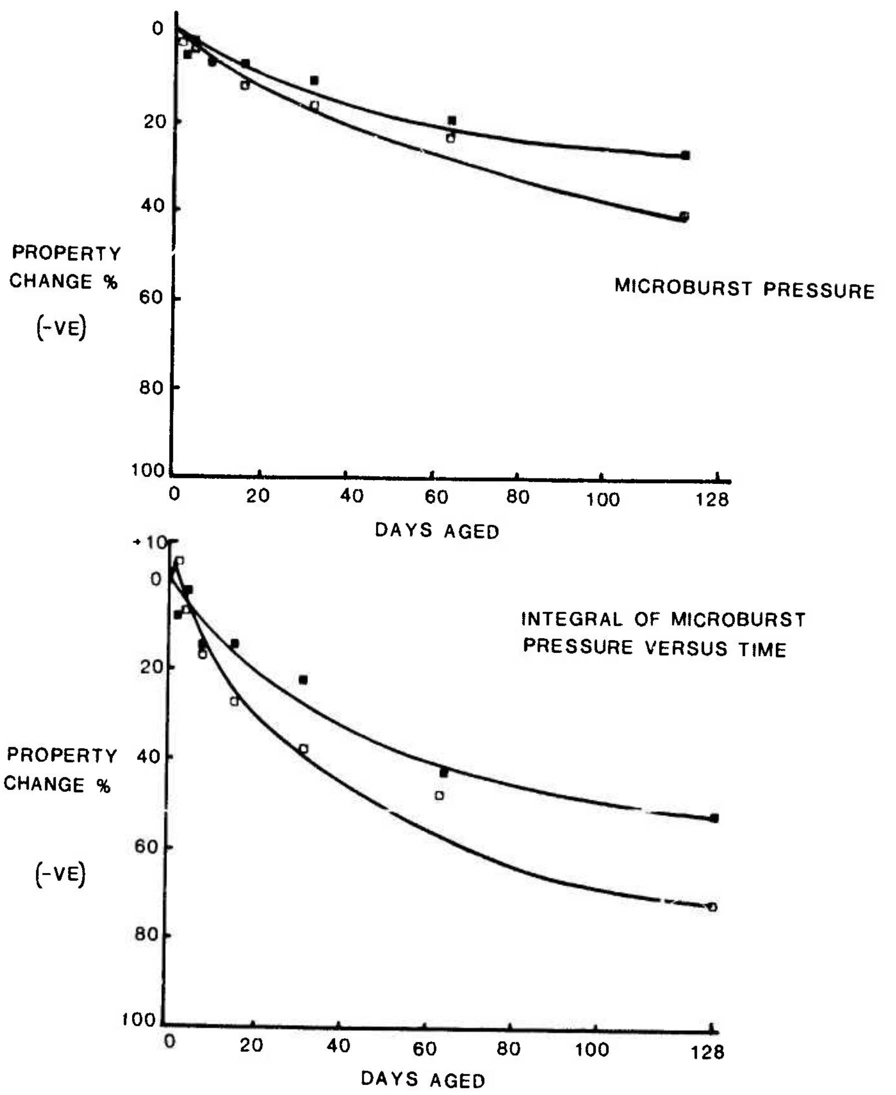


FIGURE 12. Microburst test results for undyed nylon 66 t feta thermally aged at 90°C and 100°C.
■ 90°C
□ 100°C

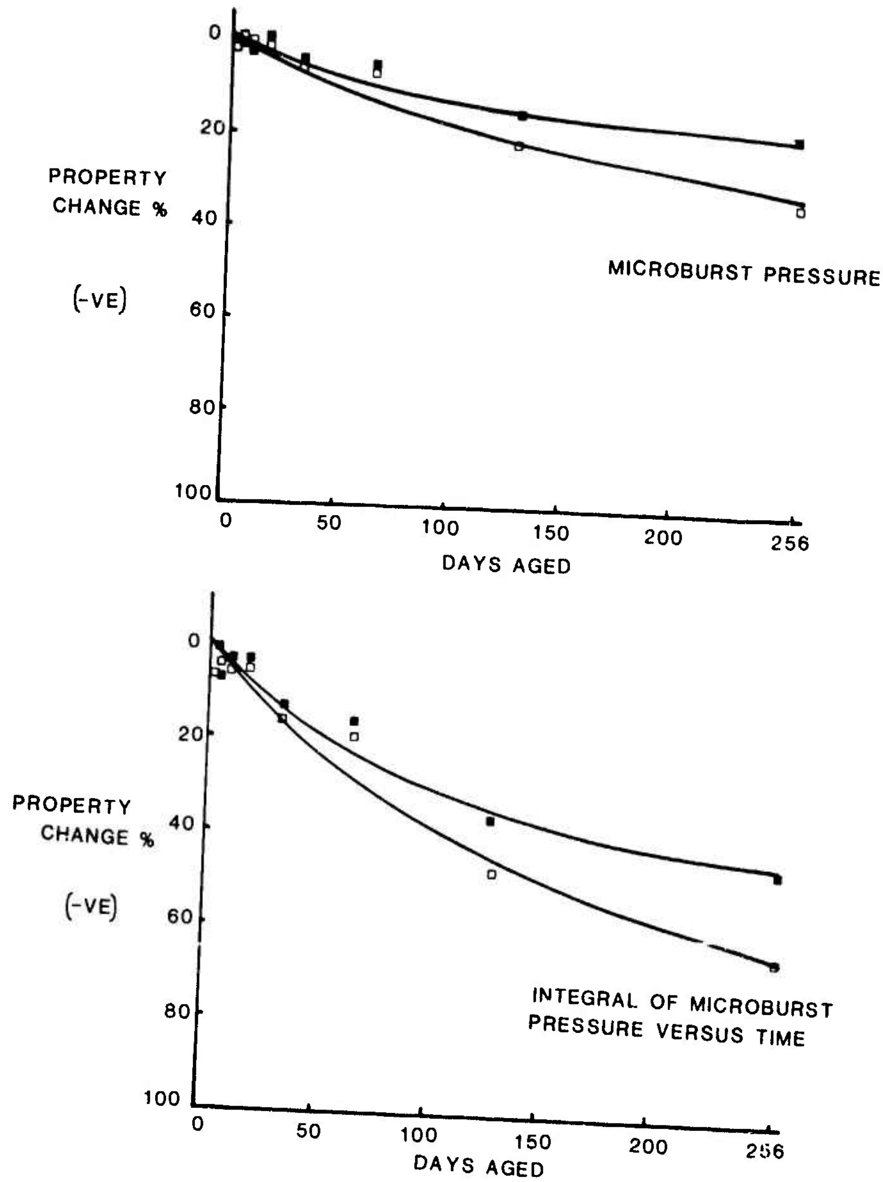


FIGURE 13. Microburst test results for nylon 66 oliv. drab dyed ripstop, thermally aged at 90°C and 100°C.

■ 90°C

□ 100°C

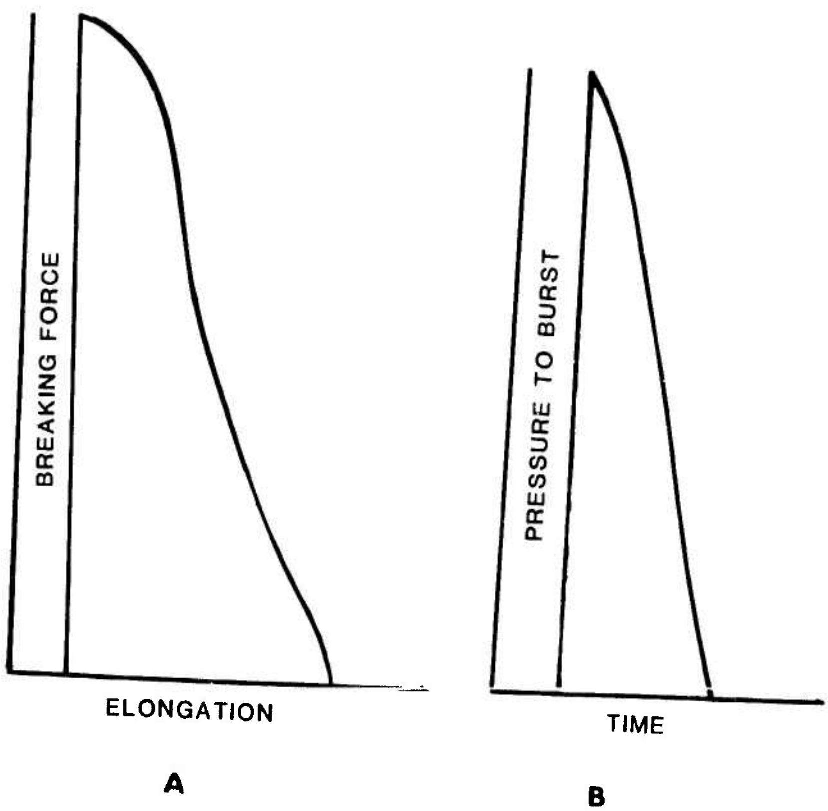
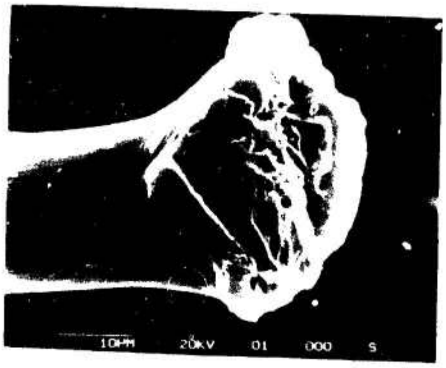


FIGURE 14. Nylon 66 taffeta, unaged.

A Breaking Force/Elongation curve.
B Pressure to Burst/Time (impulse) for microburst test.

(A)



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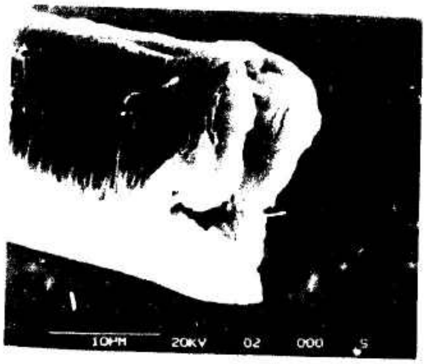

(C)

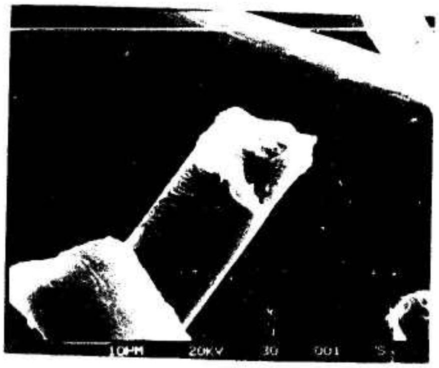

FIGURE 15. Scanning electron micrographs of unaged nylon 66 taffeta material.

(A) Ruptured tensile specimen.
(B) Ruptured Mullens burst test specimens.
(C) Ruptured Microburst test specimen.

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